NCEP/GFDL/UW/JPL Cloud and Boundary Layer CPT

NCEP: Jongil Han (PI), Ruiyu Sun

GFDL: Yi Ming (PI), Ming Zhao

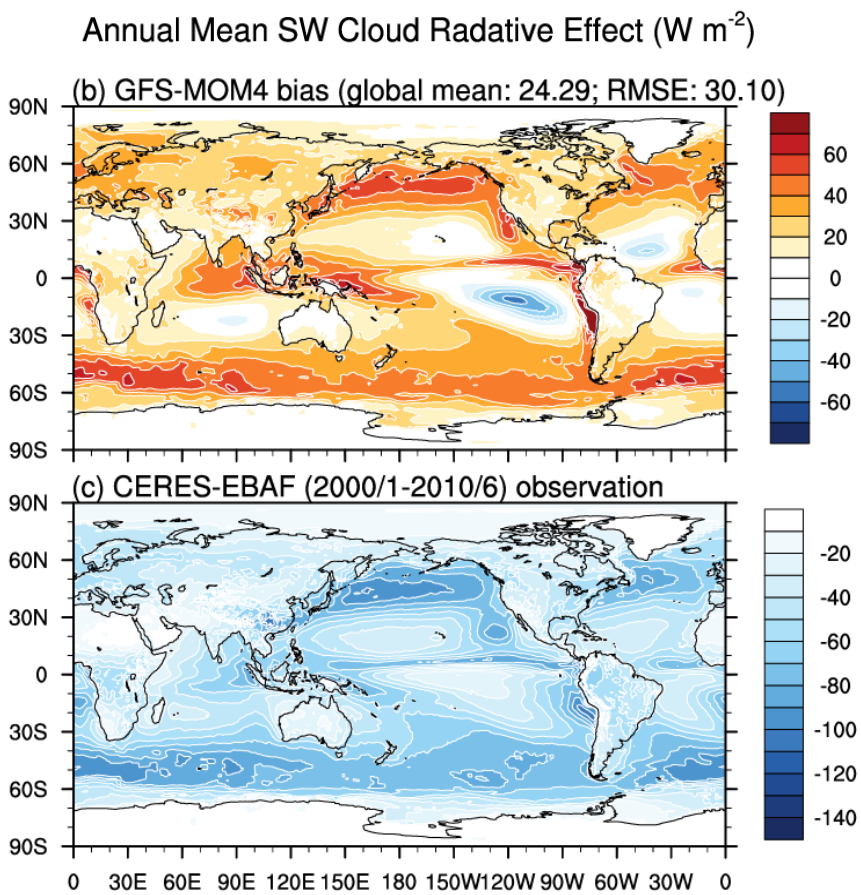
JPL: Joao Teixeira (PI), Marcin Witek

U. Washington: Chris Bretherton (Lead PI), Chris Jones

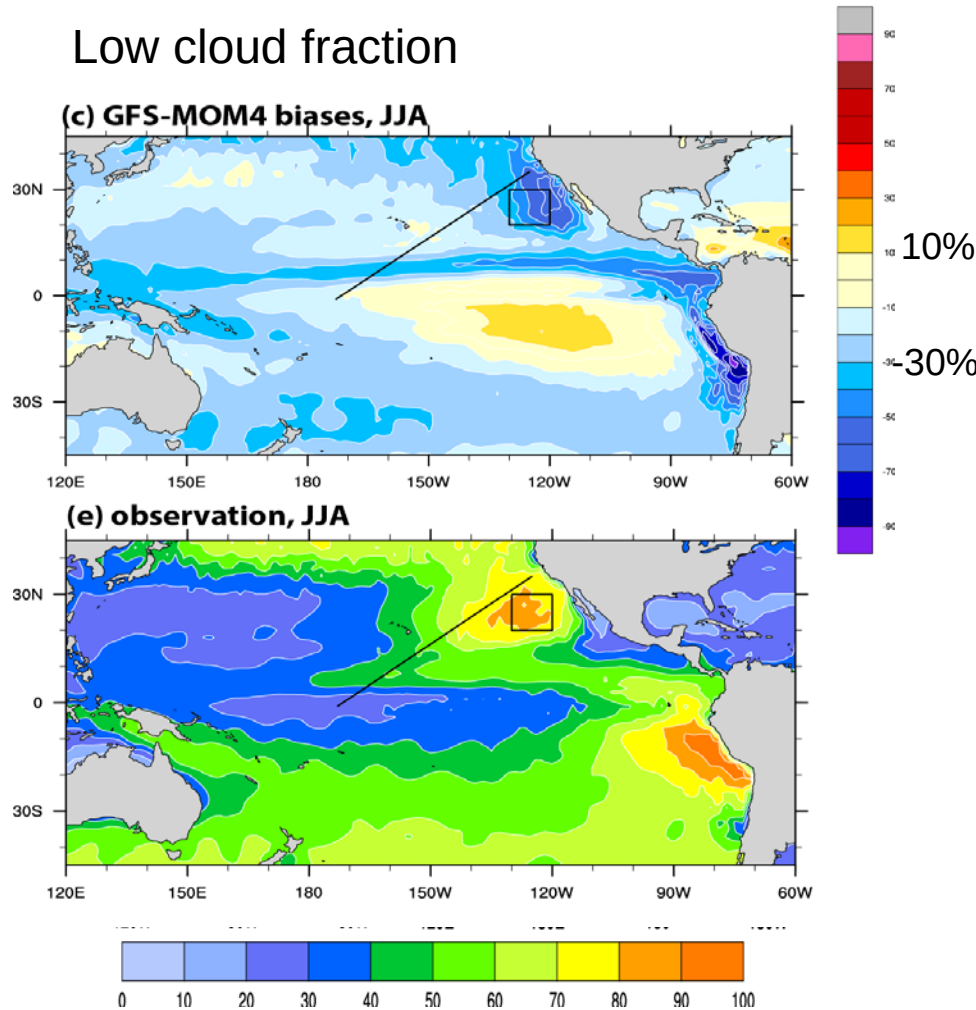
MAPP
Modeling, Analysis, Predictions, and Projections

GFS biases (2011 version)

- Too little cloud, too little reflected insolation and OLR
- 10 W m^{-2} global net radiative energy source



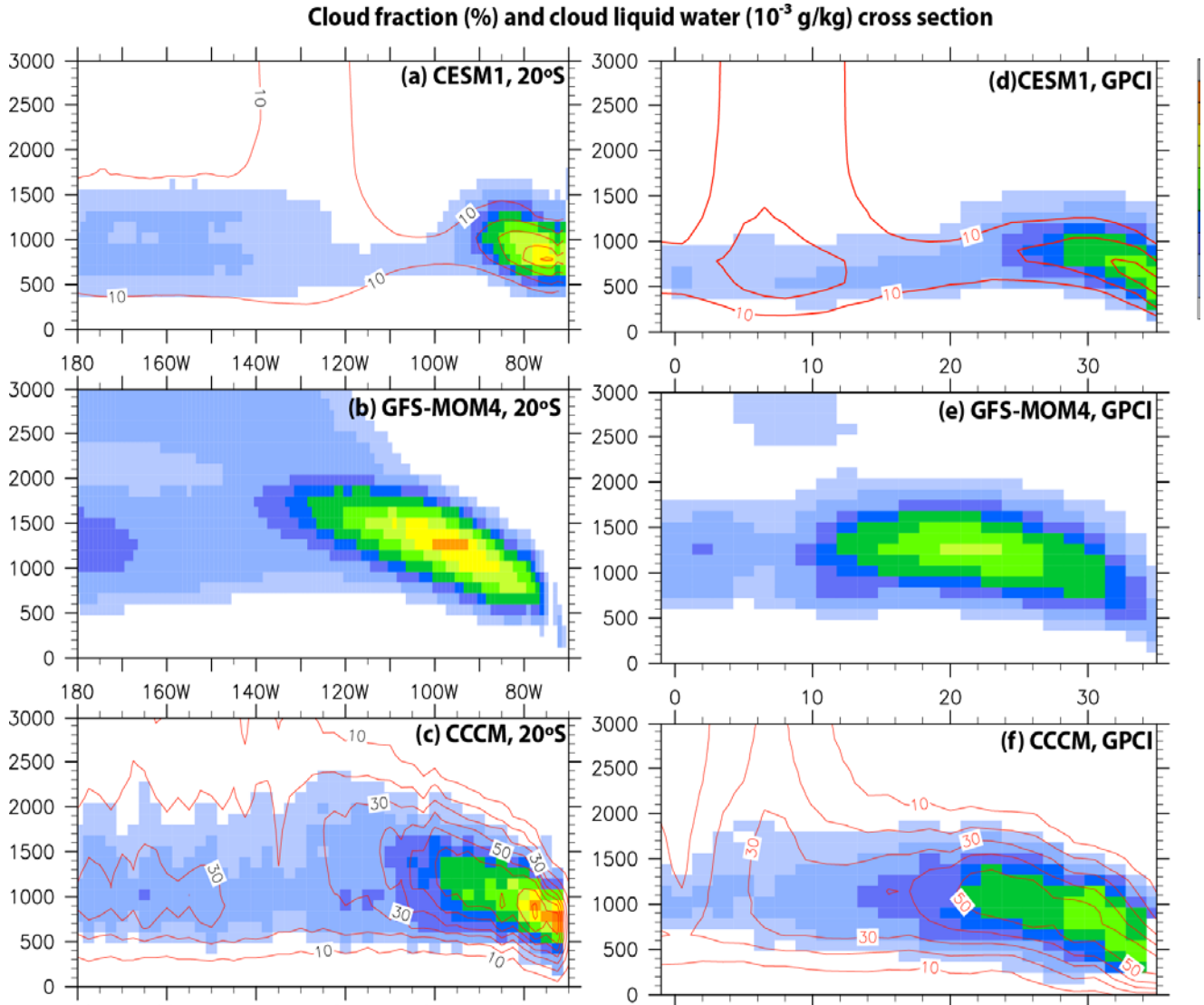
Low cloud fraction



(Xiao et al. 2013 Clim Dyn – CPT1)

Cloud vertical structure in SE Pac Sc-Cu transition

- Coupled GFS has Sc too far offshore compared to A-Train



Clouds CPT (2014-2017)

Building on previous results of Sc-Cu CPT, goals are:

- Implement a moist Eddy-Diffusion Mass-Flux (EDMF) scheme within GFS that improves operational weather and coupled climate metrics (JPL, NCEP, UW).

2014: Han et al. (2015) Hybrid EDMF (operational 1/2015)

- Improve global cloud climatology of GFS+MOM through better cloud microphysical and macrophysical schemes (NCEP, UW).

2014: Sun planned to implement GSM5 microphysics.

- Compare GFS-forecast clouds with versions of GFDL climate model run in initialized weather forecast mode (NCEP, GFDL, UW) to understand relative advantages of the moist physics parameterizations in the two models.

2014: Comparisons of daily TOA RSW, OLR for 7/2013

New CPT work in last year

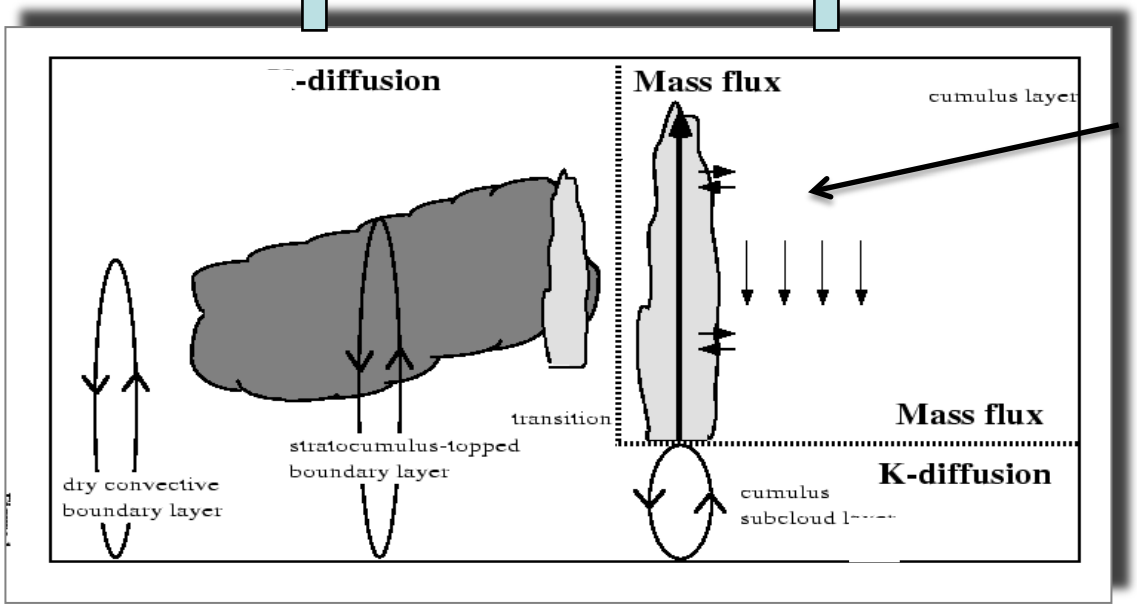
- TKE-based moist EDMF scheme (Han + JPL) for more flexible and scale-aware PBL parameterization.
- Testing new microphysics in GFS (Sun)
- Further forecast-mode cloud evaluation (UW, GFDL, NCEP)

Work in progress

(1) GFS implementation of ‘moist’ EDMF:

Transport moist variables $\varphi = \theta_l$ and q_t, dealing with Sc-top entrainment and merging with mass-flux Cu param. Much more challenging but rewarding to get right than dry EDMF.

$$\overline{w'\phi'} \cong -K\frac{\partial\overline{\phi}}{\partial z} \qquad \overline{w'\phi'} \cong M(\phi_u - \overline{\phi})$$



JPL EDMF uses multiple Cu plumes with stochastic entrainment

Development of a TKE-based EDMF PBL scheme

$$\frac{d\overline{e}}{dt} = -\frac{\partial}{\partial z}\left(\overline{w'e'} + \frac{1}{\rho}\overline{w'p'}\right) - \overline{u'w'}\frac{\partial \overline{u}}{\partial z} - \overline{v'w'}\frac{\partial \overline{v}}{\partial z} + \frac{g}{\overline{\theta}_v}\overline{w'\theta_v'} - D$$

Note that shear and buoyancy production terms of TKE are strongly influenced by the mass flux (MF) term.

$$\overline{u'w'} = -K_m \frac{\partial \overline{u}}{\partial z} + M_u(u_u - \overline{u})|_{sfc} - M_d(u_d - \overline{u})|_{Sc}$$

$$\overline{w'e'} + \frac{1}{\rho}\overline{w'p'} \approx \overline{w'e'} = -K_e \frac{\partial \overline{e}}{\partial z} + M_u(e_u - \overline{e})|_{sfc} - M_d(e_d - \overline{e})|_{Sc}$$

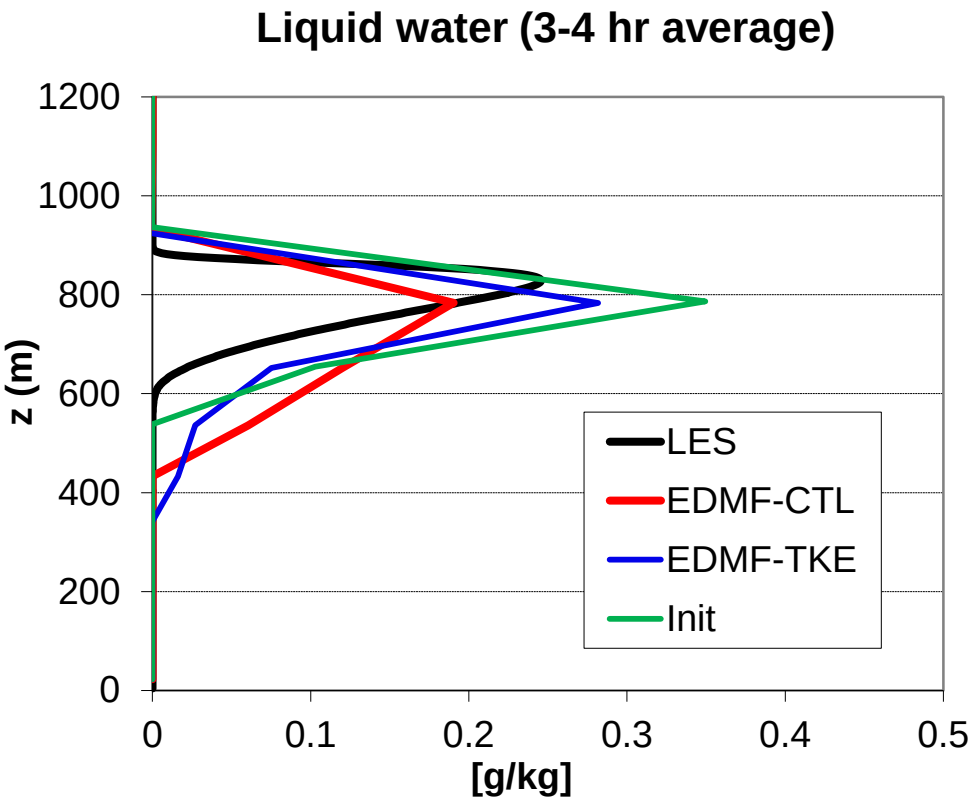
$$D = c_d \frac{\overline{e}^{3/2}}{l_d}$$

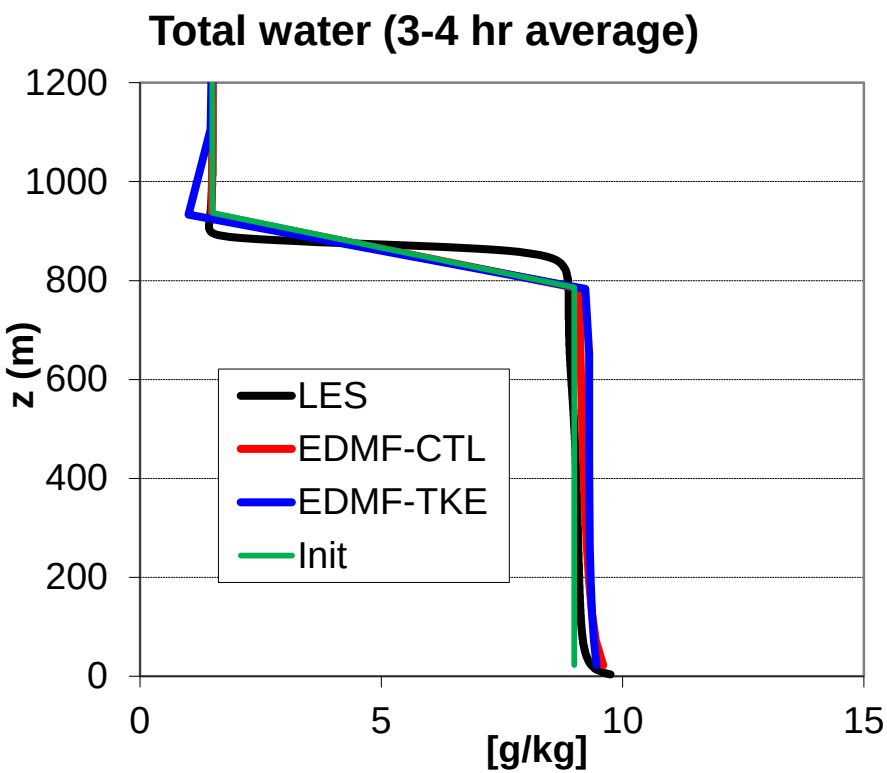
TKE dissipative rate
c_d=*0.714* (Bougeault & Lacarrere [BL], 1989)

$$c_p \frac{\partial \overline{T}}{\partial t} \approx D$$

TKE dissipative heating

GFS SCM results with current operational GFS vertical grid size (L64): DYCOMS Sc case

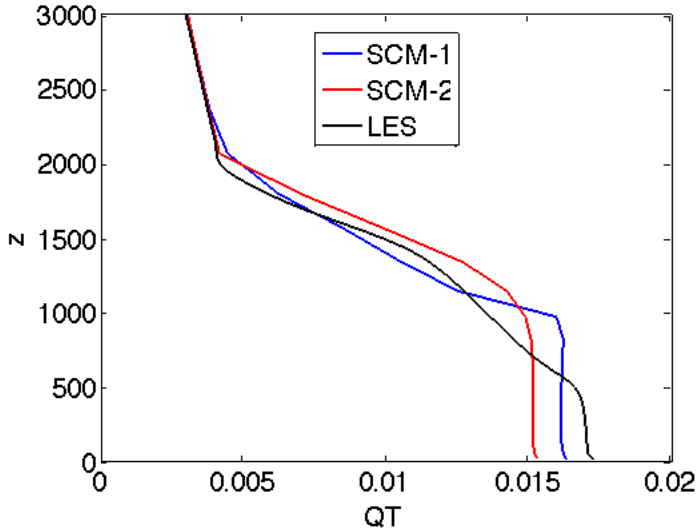


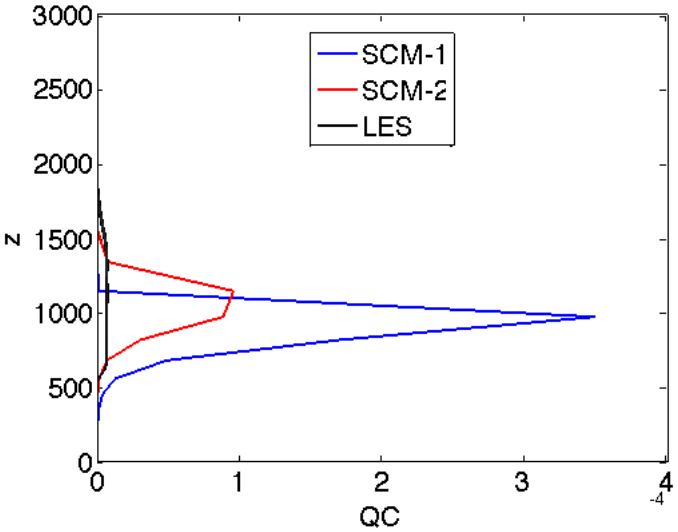


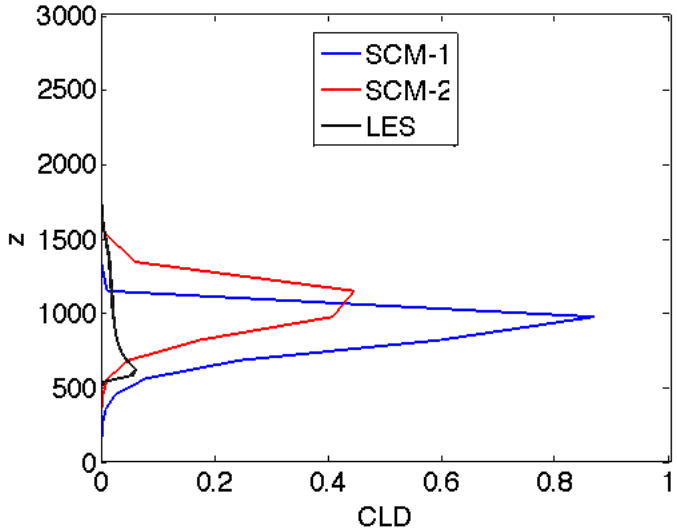
- Scheme combines current GFS EDMF with JPL approaches
- Improved SCM results vs. current GFS EDMF in all tested cases
- Soon ready to move to parallel forecast testing

JPL development of stochastic EDMF (Witek-JPL)

Multiple updraft plumes with stochastic entrainment – good for shallow Cu







GFS SCM BOMEX trade Cu case

SCM-1: Control EDCG version

SCM-2: stochastic EDMF

Stochastic EDMF improves simulation of cloud fraction and updraft liquid water content, though biases remain

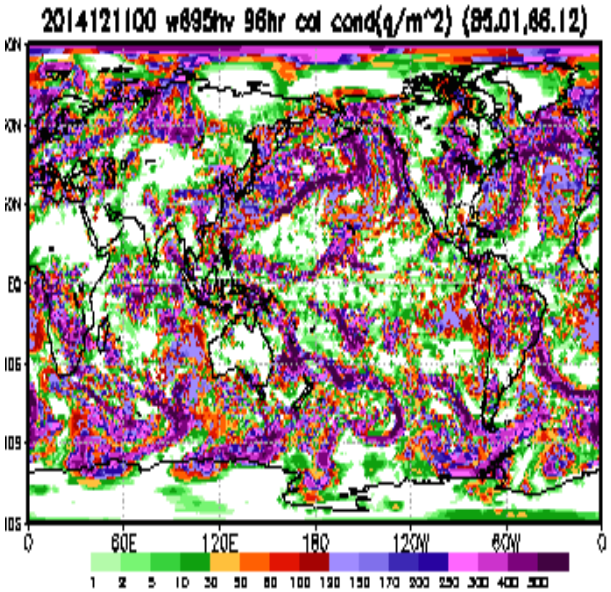
Microphysics schemes tested in GFS

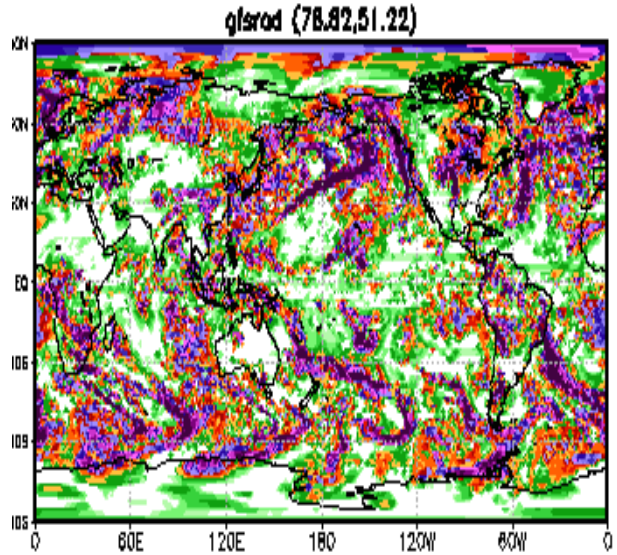
	Zhao & Carr (1997) in GFS	WSM5	WSM6	Thompson
prognostic variables	qv, qc (water or ice)	qv, ql, qi, qs, qr	+qg	qv, ql, qi, qs, qr, qg, ni, nr (double)
Condensation and evaporation	Sundqvist et al (1989)	Yau and Austin (1997)	Yau and Austin (1997)	Yau and Austin (1997)
mixed-phase clouds	No (simple ice)	Yes	Yes	Yes
precipitation sedimentation	no storage in the air and instantaneous fallout.	qi, qr, qs sediment vertically	qi, qr, qs, qg sediment vertically	qi, qr, qs, qg sediment vertically

All new schemes produce too little cloud ice and condensate. This worsens the radiative biases

Increase cloud condensate (WSM6+)

- Increase minimum cloud droplet radius for autoconversion to rain.
- Reduce ice fall speed
- Reduce collection efficiency of cloud by snow
- Add partial cloudiness and ice cloud cover
- Use autoconversion of ice to snow from Lin et. al. (1983) not RH (1983)
- Different liquid cloud drop number over land vs. over ocean
- More CLW in WSM6+ 96-hr fcsts (w695hv) vs. control GFS (gfsrad)





Bias changes:

RSW: -16➔-10

OLR: 7➔9

Net: -9➔-1

Brings GFS into radiation balance

Forecast-mode comparison of GFS, GFDL

Goal: Can we learn by comparing clouds in models and obs when large-scale dynamics haven't yet drifted far from reality?

Analyzed period: July 2013

GFS: Daily forecasts with operational (T574L64), pre-op hi-res (T1534L64) versions (O and P)

GFDL: Daily 3-day forecasts from operational GFS analysis using AM3 (2° L48) and AM4a2 (pilot version, ~ 1° L48)

Obs: CERES daily OLR and RSW

CCCM A-train climatology (vertical cloud distribution)

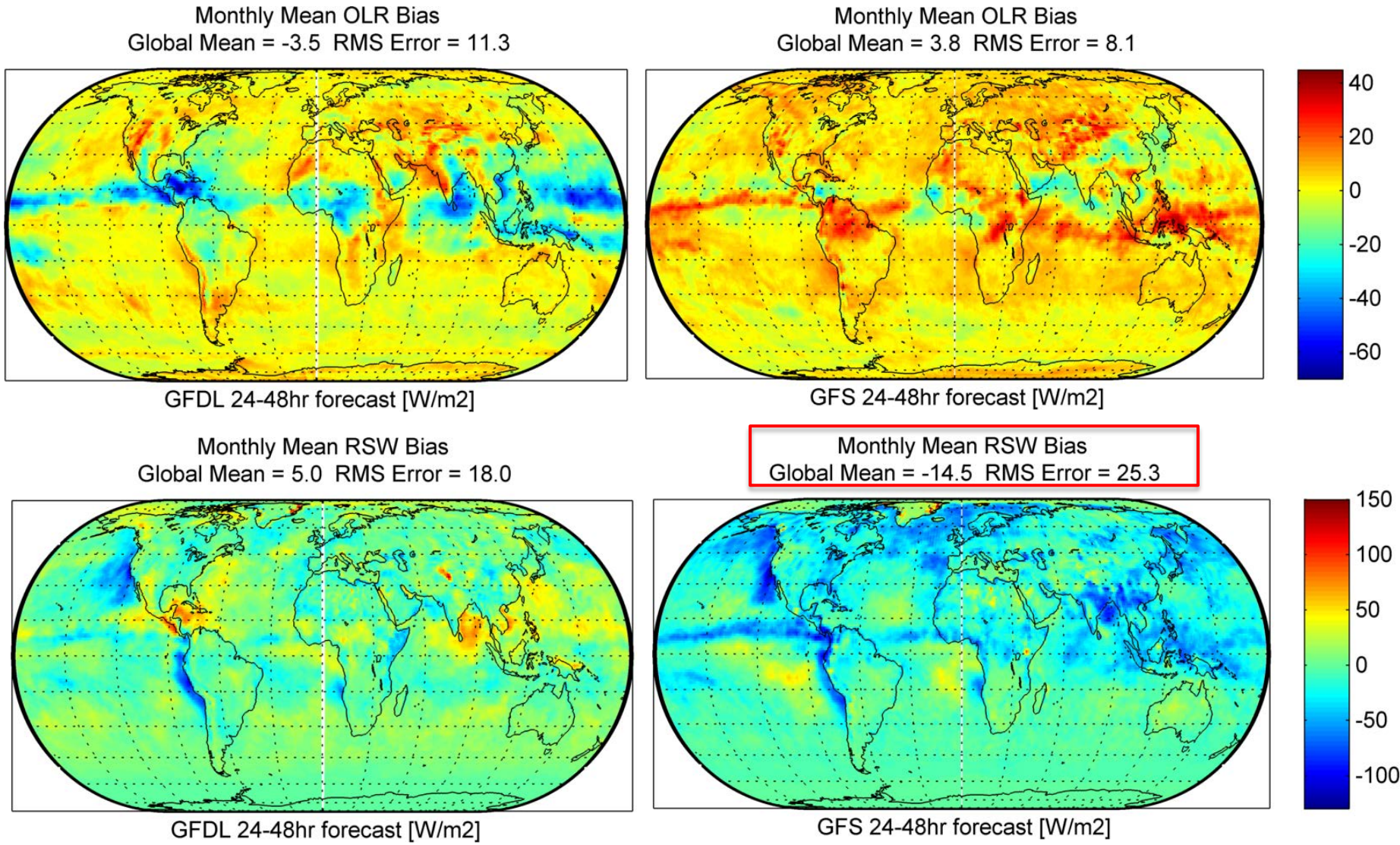
Coming: Daily SSMI LWP, daily GEOPROF CloudSat-Calipso

Results packaged into netCDF by NCEP and GFDL, analyzed by Chris Jones of UW.

All days look rather similar

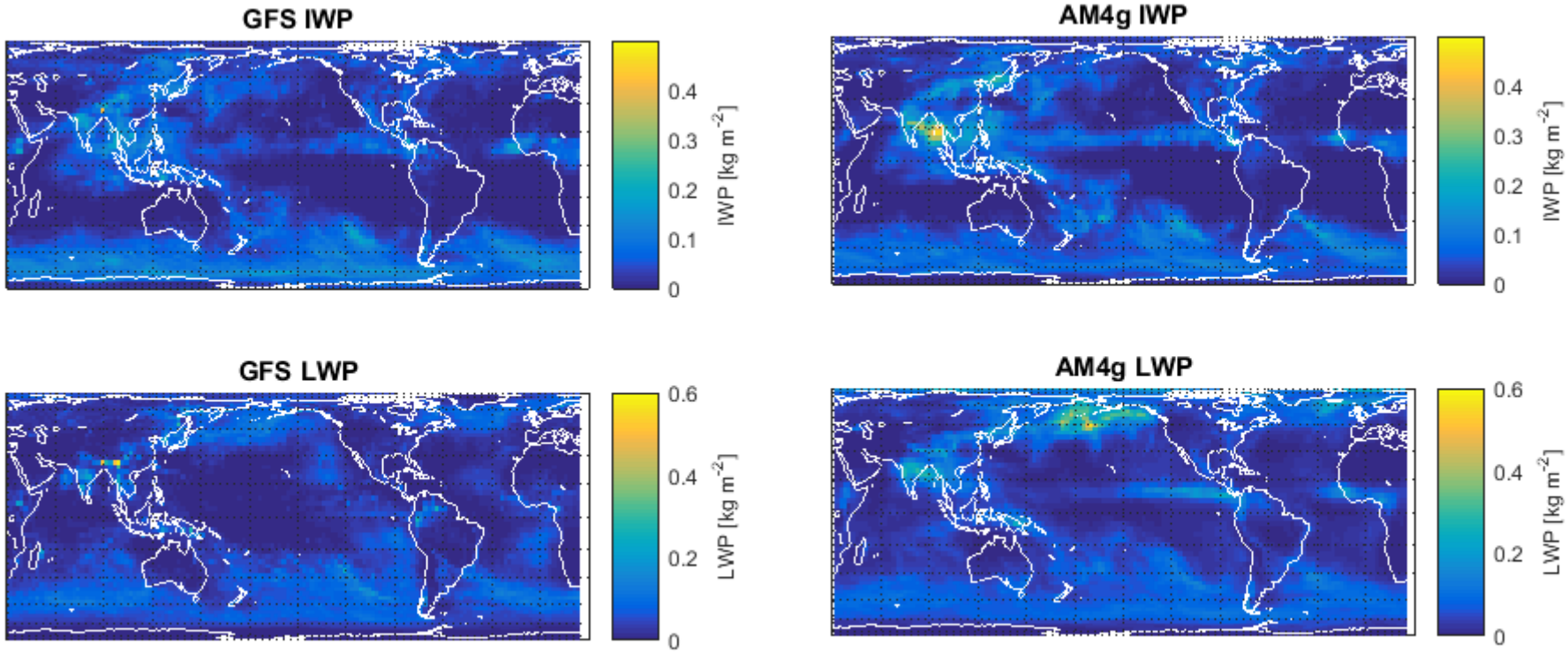
…summarized with monthly-mean 24-48 hr rad bias patterns

GFS has 10 W m^{-2} global radiative heating imbalance



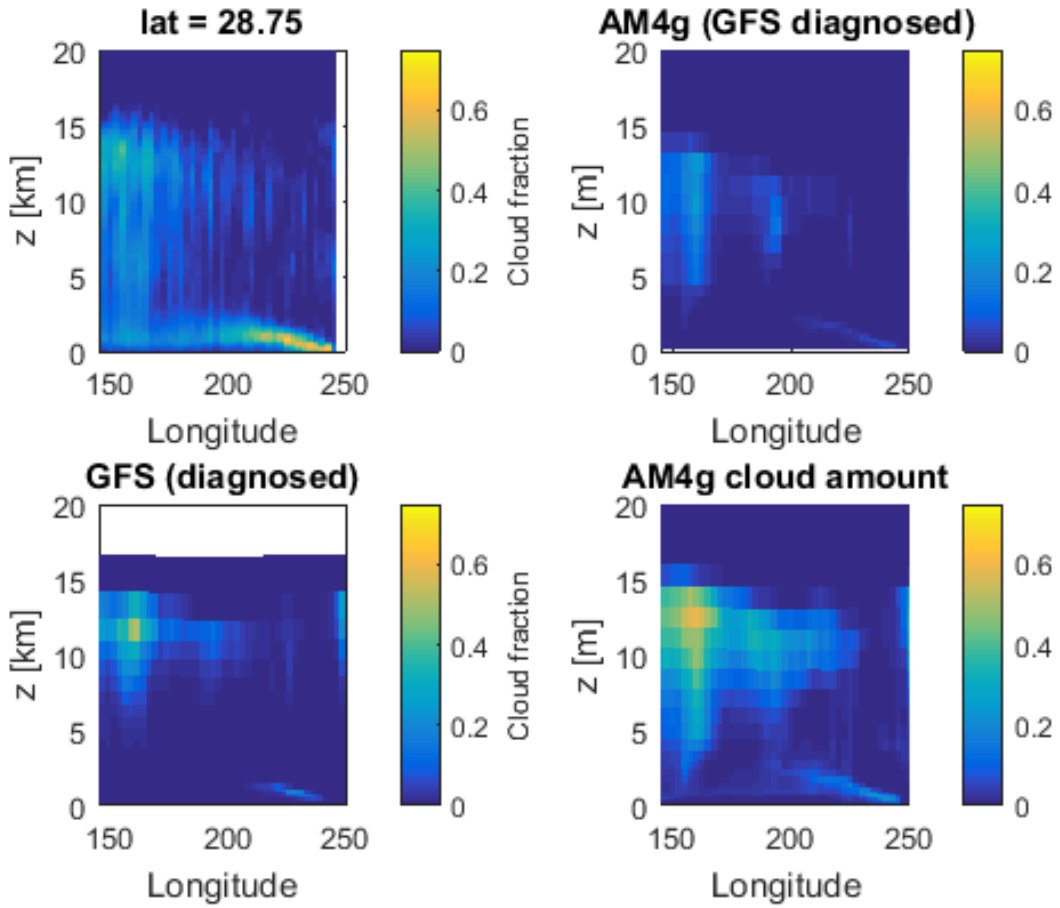
Jul 2013 mean 24-48 hr forecasts: LWP and IWP

- GFS has comparable LWP and IWP to GFDL models
  ➔ Condensate phase/amount not the reason for RSW bias



24-48 hr forecasts vs. CCCM obs

- E Pacific, lats from 0-65N, cloud cover vs. longitude
- At all lats, GFS has too little cloud
- AM4 is better, but were AM4's cloud fraction diagnosed using GFS formula, it would also be too small.



Coupled seasonal forecasts?

- Our CPT will be happy to include testing with a coupled seasonal forecast ‘test-harness’ when the software infrastructure is in place at EMC to do this.
- In the meanwhile, our strategy is to use 1-7 day parallel forecast testing for assessing model improvements – since cloud biases show up in one day, this is a useful (but incomplete) path forward.

Conclusions

- New TKE-based EDMF scheme promising in single-column tests, including for stratocumulus.
- Improved microphysics have some impact on GFS-simulated clouds, the main cloud/radiation biases remain.
- This and forecast-mode testing suggest these biases may be due to GFS radiative cloud fraction scheme.
- Removing them may require also reducing compensating model errors to retain GFS 1-7 day forecast skill.